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Scientific Article

Effect of shading on the dynamics and weed interference in organic arugula crop

Efeito do sombreamento na dinâmica e interferência de plantas daninhas na cultura da rúcula orgânica

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ABSTRACT - The use of screened structures is an alternative for reducing light, creating an ideal microclimate for vegetable development. In this sense, the objective of this research was to evaluate the effect of shading caused by the protected environment on the dynamics and period of weed control in organic arugula crops. Two experiments were carried out using a randomized block design with three replications in a split-plot scheme. The first experiment was conducted under full light conditions, and the second experiment was conducted in a shaded environment with a 35% reduction in light. The *Digitaria horizontalis* Willd and *Amaranthus spinosus* L. having the highest density in the uncovered system and the protected environment, respectively. The lack of weed control reduced arugula productivity by 52 and 80% in systems with and without a protected environment, respectively. The critical interference prevention period (CIPP) for arugula in an uncovered environment was 8–29 and 8–26 days after transplant (DAT), considering an acceptable production reduction of 2.5 and 5%, respectively. The protected environment reduced the CIPP of arugula to 20–39 and 20–31 DAT for acceptable production reductions of 2.5 and 5%, respectively. The use of the protected environment changed the dynamics of the species and reduced the period of weed control in organic arugula by 3 and 8 days, considering an acceptable production reduction of 2.5 and 5%, respectively.

Keywords: *Eruca sativa* Mill. Protected environment. Competition.

RESUMO - O uso de estruturas teladas tem sido uma alternativa para redução da luminosidade, criando um microclima ideal para o desenvolvimento de hortaliças. Neste sentido, o objetivo desta pesquisa foi avaliar o efeito do sombreamento provocado pelo ambiente sombreado, sobre a dinâmica e os períodos de controle de plantas daninhas na cultura da rúcula orgânica. Dois experimentos foram realizados utilizando o delineamento em blocos ao acaso, com três repetições em esquema de parcela subdivididas. O primeiro experimento foi conduzido sob condição de luminosidade total e o segundo experimento, em ambiente sombreado com redução da luminosidade em 35%. A *Digitaria horizontalis* Willd e a *Amaranthus spinosus* L. foram as espécies com maior densidade no sistema descoberto e ambiente protegido, respectivamente. A ausência de controle das plantas daninhas reduziu em 52 e 80% a produtividade da rúcula nos sistemas com e sem ambiente sombreado, respectivamente. O Período Crítico de Prevenção a Interferência (PCPI) da rúcula em ambiente descoberto foi do 8° ao 29° e 8º ao 26º dia após o transplantio (DAT), considerando redução da produção aceitável de 2,5 e 5%, respectivamente. O ambiente sombreado reduziu o PCPI da rúcula para 20° ao 39° e 20º ao 31º DAT para redução da produção aceitável de 2,5 e 5%, respectivamente. A utilização do ambiente protegido alterou a dinâmica das espécies e diminuiu o período de controle de plantas daninhas na cultura da rúcula orgânica em 2,5 e 7,6 dias, considerando redução da produção aceitável de 2,5 e 5%, respectivamente.

Palavras-chave: *Eruca sativa* Mill. Ambiente sombreado. Competição.

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INTRODUCTION

Arugula (*Eruca sativa* Mill.) is a species native to the Mediterranean region and belongs to the Brassicaceae family. It has phytochemical properties, such as vitamin C, fiber, carotenoids, glucosinolates, and flavonoids, which are associated with reducing the risk of heart attacks and cancer (ALRUWAIH; YAYLAYAN, 2017; BELL et al., 2017; CHUN et al., 2017). In addition to its use in food, arugula has shown itself to be a promising crop in the areas of second-generation biofuel and is used in the biological control of plant nematodes (NTALLI et al., 2018; RAHIMI et al., 2018). Due to these factors, economic interest in this crop worldwide has increased in recent years, and it can be grown in conventional and organic production systems (BELL et al., 2016).

Global interest in the organic production system is mainly due to concerns about the environment and food safety, as it does not use pesticides or chemical fertilizers. According to the 25th edition of the yearbook "The World of Organic Agriculture", published by the Research Institute for Organic Agriculture (FiBL) and IFOAM – Organics International, organic agriculture occupied approximately 96 million hectares in 2022, representing about 2% of the world's agricultural area, with a global market of approximately EUR 135 billion (WILLER; TRÁVNÍČEK; SCHLATTER, 2024).

To improve environmental conditions to favor arugula development, a shaded environment has been used as a management practice mainly in the Brazilian semi-arid region due to the high temperature and light conditions characteristic of this region. Under these environmental conditions, arugula reduces the size of its leaves, increases its pungency, modifies its texture, and promotes early flowering, characteristics that make the commercialization of this vegetable unfeasible (STEINDAL et al., 2015).

Although a shaded environment improves microclimatic conditions for crops, such as reducing temperature and water stress, it can also be detrimental to the development of some weeds, especially those adapted to high light intensities (NATHALIE et al., 2020). Lower light availability and resource competition in shaded environments tend to limit the growth and spread of photo-dependent weed species. However, restricting chemical herbicide use still represents a challenge, requiring control strategies to avoid impacts on production costs (LINS et al., 2021; MONTEIRO et al., 2021).

Once the critical interference prevention period (CIPP) has been determined, we can use management practices aimed at reducing this period of interference to increase cultivation efficiency and optimize production costs (REGINALDO et al., 2021). Practices such as plant density (JHA et al., 2017), choosing the appropriate cultivar for the planting region (LINS et al., 2019), and fertilization promote rapid crop development, causing the canopy to close, limiting the light intensity between plants, and discouraging weed development, which consequently reduces the control period and number of necessary weedings (FREITAS et al., 2021; FREITAS SOUZA et al., 2021).

The limitation of light promoted by the shaded environment improves its productive and qualitative properties, making the crop more competitive with weeds (AMEENA et al., 2024), in addition to being able to interfere positively or negatively with the weed species present in the seed bank. Based on these aspects, we hypothesized that the use of a shaded environment in arugula crops in an organic system can reduce CIPP and alter weed dynamics. Therefore, this study aimed to evaluate the effect of reduced luminosity caused by the shaded environment on CIPP and on the dynamics of weed species in organic arugula crops. Based on these aspects, we hypothesized that the use of a shaded environment in arugula crops in an organic system can reduce the CIPP and alter weed dynamics. Therefore, this study aimed to evaluate the effect of a light reduction caused by the shaded environment on CIPP and the dynamics of weed species in organic arugula crops.

MATERIAL AND METHODS

The field trials were carried out on an organic farm in the municipality of Governador Dix-Sept Rosado, RN, located at 5°18'48''S latitude and 37°26'34''W longitude from 05/06/2017 to 06/17/2017. The approximate altitude is 20 m, and the climate is classified as DdAa', according to Thornthwaite (CARMO FILHO; ESPÍNOLA SOBRINHO; MAIA NETO, 1991). The areas used in this study had been in productive activity in the organic system for more than 8 years, and all cultural treatments were carried out in accordance with the production practices adopted by the property. The average meteorological data collected during the period in which the experiments were carried out are shown in Figure 1.

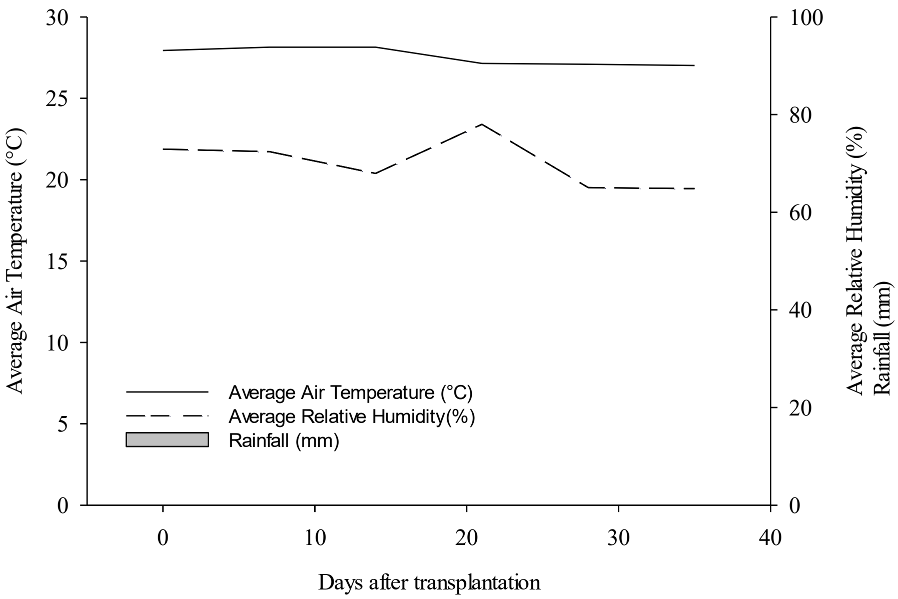

Figure 1. Average values of temperatures (ºC), maximum and minimum air temperatures, relative air humidity (%) and rainfall (mm) from 05/06/2017 to 06/17/2017. Source: INMET Automatic Meteorological Station, and rain gauge installed on the agricultural property.

The soil in the experimental area is classified as Rêndzico Chernosol, with a clayey-loam texture, and its chemical composition is expressed in Table 1. The beds were prepared using a rotary hoe, leveled, and fertilized with humus at a dose of 5 kg m^{-2}.

To obtain the seedlings, seeds of the broadleaf arugula variety were used. The seeds were planted in polystyrene trays filled with humus, manufactured on rural property, with approximately nine seeds in each cell. The trays were stored in a greenhouse for 18 days. Thinning was carried out at 8 days after planting (DAP), maintaining approximately 5 seedlings per cell. At 18 DAP, the seedlings were transplanted to the beds following a spacing of 0.15 × 0.10 m.

Table 1. Soil characterization regarding chemical attributes.

pH	P	K	Ca^{2+}	Mg^{2+}	SB	CTC	V	MO	N
H_2O	------- mg dm^{-3} -------		-------------------- cmol$_c$ dm^{-3} --------------------				%	------- g dm^{-3} ------	
8.0	47.23	1706.13	15.46	8.65	33.00	33.00	100	38.06	2.24

* pH: Hydrogen potential; P: Phosphorus; K: Potassium; Ca^{2+}: Calcium; Mg^{2+}: Magnesium; SB: Sum of Bases; CEC: Cation Exchange Capacity; V: Base Saturation; OM: Organic Matter; N: Nitrogen.

Two experiments were developed in a randomized block design with three replications. One was conducted under full light conditions and the other in a shaded environment with a screen that reduced light by 35%. The screen used was black Monofilament Nylon (Sombrite®), with UV ray blocks attached to metal rods at a height of 2.5 m. The treatments were arranged in a split-plot scheme, with plots representing coexistence or control of weeds, and subplots representing coexistence/control periods of 0, 7, 14, 21, 28, and 35 days after transplant (DAT). The experimental unit evaluated measured 1.73 m² and contained 90 plants. The useful area was composed of 2 central rows, totaling 72 plants.

The irrigation system used was a micro-sprinkler, with a flow rate of 36 L h^{-1}, spaced 3 m apart, with two 30-min irrigation shifts totaling 14 mm, according to the management adopted by the producer. The subplots were manually weeded in each corresponding evaluation period.

At the end of each coexistence period, the weeds present in the subplots were collected in sample areas of 0.25 m^2. After collection, they were counted and visually classified by species, based on the practical experience of the evaluators, to determine density and dry matter.

To determine dry matter, the classified samples were placed in paper bags and dried in a forced circulation oven at 65°C until they reached a constant weight.

The arugula plants were harvested, counted, and weighed at 35 DAT to measure production and estimate productivity. The average productivity data (kg ha^{-1}) of the treatments at different levels of control and coexistence with the weeds were converted to relative productivity. The data were subjected to regression analysis using Equation 1:

$$y = \frac{A + (B - A)}{1 + \left(\frac{X}{C}\right)^{-D}} \quad (1)$$

In this equation, *y* represents relative productivity; *X* represents days after emergence; *A*, *B*, *C*, and *D* are parameters of the logistic equation; *A* and *B* correspond to the minimum and maximum values; *C* is the inflection point 50% between the minimum and maximum values; and *D* is the slope of the curve at the inflection point (KNEZEVIC; DATTA, 2015). The determination of the period before interference (PBI), the total interference prevention period (TIPP), and the critical interference prevention period (CIPP) for losses of 2.5, 5.0, and 10.0% was carried out based on the coexistence/control periods evaluated. PBI was identified as the initial period without significant losses, while TIPP corresponded to the final control limit necessary to avoid losses exceeding pre-established levels. CIPP was defined as the interval between PBI and TIPP, which is the critical period for effective weed control.

For regression analysis and construction of graphs of weed dry matter and interference periods, SigmaPlot 12.0® software was used.

RESULTS AND DISCUSSION

The weed species that occurred in the research area were: *Aeschynomene rudis* Benth (Angiquinho), *Alternanthera tenella* Colla (Apaga-fogo), *Amaranthus spinosus* L. (Caruru), *Amaranthus hybridus* L. (Caruru-roxo), *Commelina benghalensis* Linn. (Trapoeraba), *Cynodon dactylon* L. (Grama-seda), *Cyperus rotundus* L. (Tiririca), *Digitaria horizontalis* Willd. (Capim-colchão), *Eleusine indica* L. Gaertn. (Capim-pé-de-galinha), *Ipomoea triloba* L. (Corda-de-viola), *Macroptilium lathyroides* L. (Feijão-de-rola), *Physalis angulata* L. (Juá-de-capote), *Phyllanthus niruri* L. (Quebra-pedra), *Portulaca oleracea* L. (Beldroega), *Senna obtusifolia* L. (Mata-pasto), *Sida cordifolia* Linn. (Malva-sida), and *Trianthema portulacastrum* L. (Bredo).

The use of shading altered the amount of total dry matter (Figure 2) and the weed species density (Table 2). The predominant species in the environment without the screen structure were *E. indica* L. Gaertn., *A. spinosus* L., *T. portulacastrum* L., *C. benghalensis* Linn., and *D. horizontalis* Willd, the latter being the species that accumulated the largest amount of dry matter. The use of the shade screen modified the incidence of weed species, with *A. spinosus* L. as the dominant species accumulating the largest amount of dry matter and highest density, followed by *D. horizontalis* Willd and *E. indica* L. Gaertn.

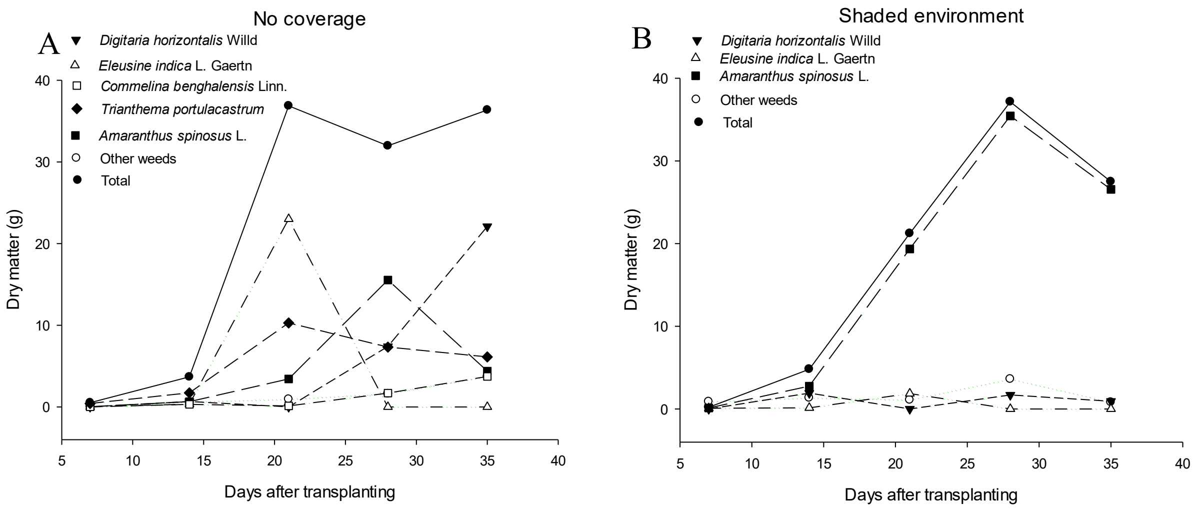

Figure 2. Dry matter (g) of weeds growing alongside organic arugula, evaluated under growing conditions without cover (A) and in a shaded environment (B), at 7, 14, 21, 28, and 35 days after transplanting.

Table 2. Average density of dominant weeds at 35 days after transplanting.

Treatment	Weed	Photosynthetic system	Density (Plants m⁻²)
No coverage	*Digitaria horizontalis* Willd	C4	52
	Trianthema portulacastrum L.	C4	60
	Amaranthus spinosus L.	C4	24
	Eleusine indica L. Gaertn	C4	0
	Commelina benghalensis Linn.	C3	4
	Other weeds	-	44
Shaded environment	*Amaranthus spinosus* L.	C4	68
	Digitaria horizontalis Willd	C4	8
	Commelina benghalensis Linn.	C3	0
	Other weeds	-	16

A dominance transition effect was observed in the uncovered environment, where until 21 DAT, the dominant species was *E. indica* L. Gaertn., and afterwards, there was a reduction in its dry matter, with the environment dominated by *A. spinosus* L. at 28 DAT and *D. horizontalis* Willd at the end of the cycle at 35 DAT (Figure 2A). This change in dominance may have occurred because the crop closed its canopy, shading the environment and harming the development of *E. indica* L. Gaertn, reducing its density and dry matter accumulation while favoring the development of *D. horizontalis* Willd, demonstrating that this species is more adapted to shading. Although both species are C4, the difference in response to shading and adaptive strategies may explain why *D. horizontalis* is more adapted to shaded environments than *Eleusine indica*. This differentiation allows *D. horizontalis* to maintain or even increase its development, even when the crop canopy shades the environment (RAIMONDI et al., 2014).

When analyzing the species occurrence in uncovered and shaded environments, except for *C. benghalensis* Linn., which presented the lowest total dry matter accumulation (3.74 g) in the last collection in the uncovered environment, all other dominant plants in the studied systems were classified as species with C4 photosynthetic metabolism (Table 2).

In a high light intensity environment, plants containing C4 metabolism tend to have greater photosynthetic and productive capacity than C3 plants. This occurs due to the suppression of the oxygenase activity of the enzyme ribulose-1,5-bisphosphate carboxylase-oxygenase (Rubisco), provided by a biochemical mechanism that concentrates CO_2 in the cells of the Kranz sheath, where Rubisco is expressed (TAIZ; ZEIGER, 2013; BELLASIO; GRIFFITHS, 2014; TSUTSUMI et al., 2017). This effect was observed in shaded environments, where *D. horizontalis* Willd, a species that was highly competitive in uncovered conditions, had a density of 52 plants m^{-2} and total dry matter accumulation of 56.15% (22.10 g) and reduced its density to 8 plants m^{-2} and accumulated only 0.94 g of dry matter when exposed to the shaded environment (Figure 2A, Table 2). The effects of shading on *E. indica* L. Gaertn. and *T. portulacastrum* L. were even greater since the incidence of these plants was not detected at the last collection (Figure 2B, Table 2).

The reduction in luminosity provided by the shaded environment favored the growth of *A. spinosus* L., which was responsible for the accumulation of 96.58% (26.55 g) of the total dry matter in the last collection and a density of 68 plants m^{-2} (Figure 2B, Table 2). A possible explanation for this is that this species belongs to the Amaranthaceae family. Studies have reported that species belonging to this botanical family have a morphophysiological transition mechanism between C3 and C4 (SÁNCHEZ-DEL PINO; MOTLEY; BORSCH, 2012). *A. tenella* Colla (Amaranthaceae) is a weed species that has a CO_2 compensation point and maximum photosynthetic rate due to light intensity that is intermediate between plants with classic C3 and C4 metabolism. In addition to belonging to the Amaranthaceae family, the morphological characteristics of *A. spinosus* L., such as the arrangement and inclination of the leaves and the height of the plant, favor light capture and consequently the greater growth of *A. spinosus* in shaded environments compared to Poaceae species (TSUTSUMI et al., 2017).

The relative yield data followed a logistic trend with four parameters, and the proposed model was adequate since it presented a high R^2 value (Table 3).

Table 3. Regression parameter estimates by treatment for the four-parameter log-logistic model characterizing the influence of weed interference duration on relative yield for organic arugula crops.

Treatment	Curve	Regression parameters				
		A	*B*	*C*	*D*	*r²*
No coverage	No competition	11.43	106.82	11.87	2.5	0.96
	With competition	14.05	109.09	15.26	-2.85	0.99
Shaded environment	No competition	15.38	98.79	15.93	4.69	0.99
	With competition	49.48	102.48	22.9	-15.75	0.99

The lack of weed control reduced arugula productivity by 80.01 and 51.69% in uncovered and shaded environments, respectively (Figure 3). The use of shading in arugula production created a microclimate that favored crop development, increasing its competitive capacity. For this reason, the reduction in productivity in this environment was smaller than when cultivated without the use of cover. Another factor that may have contributed to the increase in competition capacity is the high crop density, which accelerated canopy closure and prevented weed development (DARYANTO; WANG; JACINTHE, 2017).

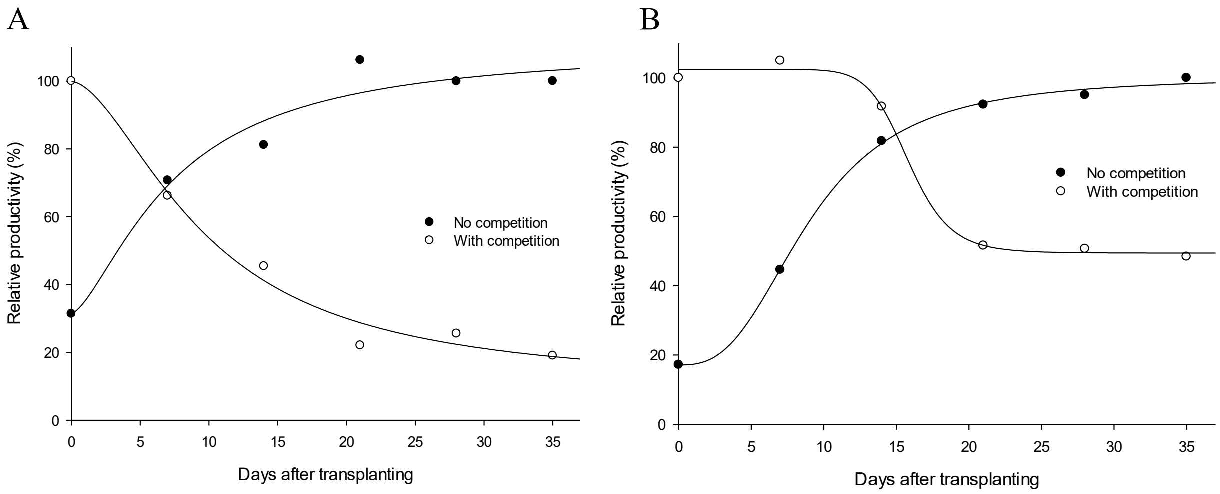

Figure 3. Relative productivity of organic arugula as a function of days after transplanting at different levels of coexistence in no coverage (A) and shaded environment (B).

The shaded environment reduced weed density by 34.23% and accumulated dry matter by 60.38% at the first collection. This reduction provided less initial weed interference for arugula, resulting in an increase in PBI by 11, 12, and 13 days for an acceptable reduction in productivity of 2.5, 5, and 10%, respectively (Table 4). The shaded environment had a positive effect on arugula by reducing the CIPP by 3, 8, and 9 days for an acceptable reduction in productivity of 2.5, 5, and 10%, respectively (Table 4). A CIPP lower than the PBI observed in the shaded environment reflects the lower need for weed control.

Table 4. Period prior to interference (PBI) and critical period of interference prevention (CIPP) for weed control in organic arugula crops, in an uncovered environment and in a shaded environment, according to the acceptable reduction in productivity.

Management system	Redução da produtividade (%)	Interference periods (days)		
		PBI	CIPP	TIPP
No coverage	2.5	8	22	29
	5.0	9	18	26
	10.0	10	13	22
Shaded environment	2.5	20	19	20
	5.0	21	11	21
	10.0	22	4	22

The positive effect of shading on arugula crops is attributed to the microclimate created by reduced temperature and light and higher relative humidity. These conditions are favorable for the crop, with stomata remaining open longer, inducing greater CO_2 capture, increasing its growth rate, and enabling better environment adaptation and more weed competition (MARTÍNEZ-VILALTA et al., 2014; SINCLAIR et al., 2017).

In the organic planting system, the most used weed control method is manual weeding. This practice can cost twice as much compared to the chemical control methods used in the conventional planting system (BESSETTE; ZWICKLE; WILSON, 2018; PARRY; SHRESTHA, 2018). Thus, according to the data processed in this experiment, shading modified the dynamics and period of weed control. Considering a 5% loss in productivity, the shaded environment provides the producer with a reduction in weed control for 8 days compared to management carried out in the uncovered environment. In this sense, production will be optimized since the arugula crop should be free of weeds at 20–31 DAT, while in plants without cover, weed control should be carried out at 8–26 DAT. This enables a more strategic allocation of labor, freeing up resources for other activities and promoting more effective management in organic arugula cultivation.

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CONCLUSIONS

The use of a 35% shade screen modified the dynamics of weed species in organic arugula crops. Shading reduced the critical period of weed control in arugula cultivation in an organic production system.

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